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EFFICIENCY OF THREE BINDING AGENTS ON THE IMMOBILIZATION OF CADMIUM IN SOILS UNDER MEDICINAL AND SPICE PLANTS CULTIVATION IN AGRO-FORESTRY SYSTEMS

ARLINDO FERNANDO MACIE[1*], PRABANG SETYONO[2], WIDYATMANI SIH DEWI[3], and KOMARIAH[3]

[1]Department of Agronomy and forestry engineering, Eduardo Mondlane University, Avenida do Zimbábwe, Maputo, Mozambique
[2]Lecturer at Environmental Science Department, Universitas Sebelas Maret, Surakarta, Indonesia
[3]Lecturer at Department of Agriculture of Universitas Sebelas Maret Surakarta, Indonesia.

ABSTRACT

The soil is an important resource, which sustains life on the planet. However, its contamination with Cadmium (Cd) may represent a huge threat to all the chain of living beings. Efforts have been done to minimize soil pollution with trace metals, as well as to amend those soils that are already polluted. This study was conducted aiming to determine the efficiency of three binding agents on the immobilization of Cd in three soil types collected from Karanganyar. Soil samples were collected from the topsoil (30 cm) and analyzed in the laboratory for pH, SOM, CTC, soil texture and initial Cd content before treatment. The experimental design was Completely Randomized (3 soil types; 3 adsorbents; 3 replications), and incubated for 24 days in the laboratory. After incubation, pH and Cd content were measured and ANOVA and Tukey's test were performed. The results showed that Dolomite was the best binding agent on immobilization of Cd (95.45%) in each soil, followed by organic fertilizer (92.64%) and charcoal (91.53%). However, in general, all the binding agents showed remarkable efficiency on Cd immobilization in the three soil types. To sum up, this research may positively boost agricultural systems, which is determinant for sustainable development, in particular in developing countries worldwide. In addition, the outcomes may have a great impact on the reduction of soil pollution with agrochemicals and heavy metals. On the other hand, there is a potential to keep and restore ecological sustainability. Apart from this, also could minimize to some extent, climate change and global warming issues through multi-planting strategies, while significantly contributing to achieving food security and economic stability, as well as addressing poverty issues in rural areas.

1 INTRODUCTION

The soil is a valuable natural resource which grants life along generations for those who possess it and others who get indirect benefits. It also plays a huge role in greenhouse gas emissions, which is a major driving factor of global climate change. Only behind the Oceans, soil is the largest carbon sink, however, land use change and non-appropriate agricultural practices are resulting in large amounts of carbon released into the atmosphere

[*] Correspondent author: arlindomacie@gmail.com

(Oertel et al. 2016). Biological agriculture combined with other sustainable systems has been seen as an alternative to cut off GHG and tackle climate change (Kolling and Teresa 2013). Soils offer a wide range of benefits including, growing plants for self-consumption and for the market. Medicinal plants cultivation has taken an advanced stage in many places due to its higher demand (Tripathy et al. 2015). Moreover, their cultivation creates markets, but more worthy than that represents a mean of conservation. Most of the plants grown in natural forests are extremely threatened by overexploitation, so it is a must to preserve them through cultivation in controlled environments. Their higher availability, lower prices in the rural areas, where people have lower incomes, and also the absence of side effects, make them much more preferred.

Despite medicinal plants considered as safe, they have been challenged by heavy metals found in soil where they grow. Such metals accumulate in the soil as residuals of agrochemicals (Li et al. 2012). One of the ubiquitous toxic elements in agricultural soils is Cadmium (Alloway 1995). It is usually added to soils through atmospheric deposition, sedimentation, parent material, industrial spots, vehicles and phosphate fertilizers, which is the main source in agricultural systems (Grant 2011). Cadmium is undesirable for humans and plants because it causes lethal disease and lowers yields in plants. The Cadmium toxicity becomes of great importance because even at lower residual content, there is still a possibility to cause adverse effects (Rehman et al. 2015). Apart from health issues, economic losses can happen as a result of banned products from certified markets. Once in the soil, Cd remains there for long years because of its long half-life (Chavez et al. 2016; Li et al. 2016).

Efforts have been made in order to control Cd mobility and bioavailability. In this field, adsorbents have been reported having good results. They make bonds with many elements considered as pollutants in the environment, preventing them from being available in the mobile form. Their use is recommended because of less or non-secondary effect when applied, most of them can be found in natural environments avoiding market costs (Angelova et al. 2015). However, what defines a good adsorbent is its capacity to bind and immobilize any pollutant expeditiously.

A number of cost-effective and environmentally friendly adsorbents have been used for Cadmium removal including biopolymers, activated carbon, metal oxides, clays, dried plant parts, microorganisms, and sewage sludge (Kumar et al. 2010). Inorganic materials usually perform better than those of organic amendments, because they are able to create extra adsorption sites and raise pH in the soil solution (Grabowska 2011). Lime has been used in pots and field trials to increase soil pH (Arunakumara et al. 2013), while organic matter adsorbs Cd through complexation of free ions (Angelova et al. 2013). On a whole, soil properties like pH, CTC, clay, SOM and soil texture define how long the Cd stay immobilized in soil. Ahmad et al. (2011) found that high SOM increased Cd absorption because of soluble hydroxides and organic acids from SOM decomposition and decrease of pH (Iranpour et al. 2014; Rattanawat et al. 2010). In other studies, Hanc et al. (2008) and Ngorwe et al. (2014), evidenced that poetry and compost increased soil pH, which is due to the sources of organic materials rich in basic cations. Hardiljeet et al. (2013), suggest that Cadmium removal could reach its maximum at the pH value of 8, however, has to be avoided because it can cause nutrient deficiency to plants due to fixation process. Furthermore, Luo et al. (2010) verified in a study that addition of compost into soil declined exchangeable Cadmium by 70%. Besides dolomite and animal manures, Charcoal is known for having good results on Cd purification. It was used by Iranpour et al. (2014) to remove Cd from wastewater and performed at 91.25% under pH 7. In Indonesia, phosphate fertilizers are largely used, and as indicated by Thomas et al. (2012), the amount of Cd in soil is a function of impurities in the fertilizers. On the other hand, the Indonesian government has not established yet any legislation that determines the limit values of Cadmium in agricultural soils for safety production. To conduct this trial we were inspired by the work of Low and Lee (1994) who studied pH on the immobilization of Cd and found that $Ca(OH)_2$ was most efficient in immobilizing Cd followed by carbonates and phosphates. Also based on Qadar et al., 2014, who state that even low Cd content in soil are still dangerous. The current research aims to determine the efficiency of Binding agents on Cd adsorption and determine their feasibility and applicability. The hope is that this study may provide alternatives to tackle Cd in soils and, guarantee safety medicinal plants cultivation and their commercialization in abroad markets, and local ones, adding product value and increase their gate price.

2 MATERIALS AND METHOD

2.1 Research location and time

The research was carried out from August 2015 up to May 2016. The investigated areas were the villages of Kemuning, Bakalan and Tamansari in the Karanganyar district, Central Java, Indonesia. The soil types of the researched places are Inceptisols, Alfisols, and Ultisols, respectively. The average of rainfall ranges from 2500 to 3500 mm/year, with the highest precipitation recorded in Kemuning district.

2.2 Soil sampling and lab analysis

Soil samples were collected and prepared according to Low and lee (1994). Lab analysis was taken in the Soil Science laboratory at Universitas Sebelas Maret. The study variables were Cation Exchange Capacity (CTC), soil pH, organic matter (OM), soil texture, and Cd content in the soil. CTC was determined through Ammonium Acetate method pH 7, followed by titration with HCl (10%) after destilation. The pH meter was used for pH-H_20, while the organic matter was determined through Wakley-Black method (Brian 2002), and soil texture by pipette method and textural triangle (Whiting et al. 2002.)

2.3 Lab trial for immobilization and extraction of Cadmium

A laboratory experiment was conducted to determine the content of exchangeable Cadmium and the immobilized one, as well as the efficiency of each binding agents. The experimental design was Completely Randomized (3 soil types X 3 binding agents X 3 replications). Three soil types (Inceptisols, Alfisols, and Ultisols were treated with three types of binding agent (Organic fertilizer from cow dung, Charcoal, and dolomite). Each soil received three different binding agents separately in triplicate, and then all the mixtures were incubated for 24 days in flask bottles of 100 ml.

After incubation, 1ml of HNO_3 and 3 ml $KClO_4$ were added and the mixtures were heated in the chamber, firstly at 80^{o}C and then the temperature was increased to 130^{o}C until the orange smoke is finished. The mixture was filtrated and then 20 ml of an extracting solution of 0.01 $Cacl_2$ was added, and finally the mobile Cd was determined through AAS (modified from Lu and Lee 1994; Ogbonna and Ogbonna 2011). Soil pH was also measured after the incubation period. Initial Cd values were determined in the binding materials. Data analysis was performed through MINITAB 16. The ANOVA was also performed at 5% of significance, and Tukey's advanced test was taken to determine the statistical difference between the three binding agents.

3 RESULTS AND DISCUSSION

3.1 Soil properties and Cadmium content in the investigated area.

The results of soil properties and Cadmium content before the incubation phase are shown in table 1. Inceptisols from Kemuning (A) are strongly acidic (pH 5.07), lower organic matter (2.71%), and are sandy clay loam. Alfisols from Bakalan (B) are slightly acidic (pH 6.27) with lower organic matter (3.07%), and are sandy loam, while Ultisols from Kerjo are almost neutral (pH 6.54) with lower organic matter content (2.12%), and are clayey soils. All the soils showed lower CTC (5-16 cmol (+)/kg/clay). The Cd content is still within the limits for agricultural soils (0.1-1.0 mg Cd/kg), however, they represent a big threat to living beings.

Table 1. Soil properties and Cd concentration in the study location

Soil	CEC	pH	OM%	CdS	Silt%	Clay%	Sand%	Texture
A	11.38	5.07	2.71	0.40	25.01	20.98	54.02	SCL
B	12.80	6.27	3.07	0.44	72.94	9.28	17.79	SL
C	15.50	6.54	2.12	0.41	19.55	58.15	22.31	Clay

Unity: CEC-cmol (+)/kg; CdS (Cd in soil-mg Cd/kg)

According to Qadar et al. (2014), even low Cd concentrations of 0.1-1.0 mg/Kg have great potentials to cause adverse effects on plant growth, metabolism, plant tissue death, hormonal and nutritional balance and affect human and animal lives (Hasan et al. 2009). Therefore, the cadmium content in soil is still below the limits, in the long run if the use of phosphate fertilizers takes place, might be unsafe growing medicinal plants in these soils as it can enter into food web through plants and animal feeding. Alloway (1995), found out that phosphate-based fertilizers produced with apatite extracted in Florida USA increased Cadmium content in the soil by 0.3-1.2 g Cd/ha/year. On the other hand, if soil pH drops down the amount of Cadmium adsorbed in the soil matrix may be released into soil solution and become readily available to plants. Another factor which can contribute to increasing mobile Cadmium in the soil solution is the lower content of soil organic matter. The high content of organic matter, as well as great values of pH and CEC, raise the adsorption of Cadmium in the soil (Lindsay 2001).

3.2 Incubation, immobilization, and extraction of Cadmium in soils.

The results of mobile Cadmium content versus soil type from three different villages of the Karanganyar district are shown in **table 2**. It is apparent that the means of Inceptisols from Kemuning (0.0372 mg Cd/kg) and Ultisols from Tamansari regarding the mobile Cadmium in soil are not statistically different, whereas the Alfisols from Bakalan village is statistically different from the previous soils. As a result, can be stated that Alfisols performed well in the immobilization of Cadmium in the way the mobile Cadmium content is the lowest amongst all.

Table 2. Advanced tukey's test for means of cadmium content in soil solution

Soil type	Cd mean
Inceptisols	0.0372 ab
Alfisols	0.0299 c
Ultisols	0.0383 a

Means followed by the same letter in the column are not statistically significant at α 5% for tukey's test

The causes of these results are still not clear how this soil (Alfisols-B, 0.0299 mg Cd/kg) has the highest initial concentration of Cadmium. Even though, the lower mobile Cadmium in soils can be justified by the content of organic matter (3.08 %, table 1). On the other hand, Alfisols may contain Iron oxides that also adsorb heavy metals (Suda and Makino 2016). Although the organic mater content is low in Alfisols, it is still by far higher compared to other soils, which in turn has high CEC value and clay content. Organic matter and clay content increase the adsorption of heavy metals, dipping down their concentration in the mobile form. The adsorption of Cd by organic matter is due to Cd-specific sites such as Carboxyl and hydroxyl ligands on soil organic matter which generate stable forms (Angelova et al. 2015; Houben et al. 2012).

In addition, the capability of an adsorbent to bind Cadmium may depend on the amount of Cadmium in soil, which is in linear to the amount of applied phosphate fertilizer, its application frequency and the time passed since the usage of agro-chemicals has started. This is in line with Anderson and Hahlim (1981), who conducted field trials with phosphate fertilizers application and found evidence that long term application of phosphate fertilizers in conventional farming, can lead to an annual increase in Cd content of the soil from 0.32 to 1.1% even if applied at normal rates. Therefore, the use of phosphate fertilizers should be limited or even avoided to prevent anthropogenic additions of Cd into soils. However, soil characteristics are still determinant on Cadmium immobilization. Moreover, despite that is not clear the contribution of the clay minerals, yet the theory confirms that Alfisols can be formed by clay minerals like, kaolinite that contains a large amount of hydroxyl edges with high affinity for cadmium (Anderson and Hahlim 1981).

Therefore, it can explain the high efficiency of Alfisols, compared to the others. The efficiency of three binding agents namely, (1) dolomite, (2) organic fertilizer, and (3) activated carbon on the immobilization of extractable and water soluble Cd was studied. The results of Tukey's Test shown in **table 3**, evidenced that dolomite was superior in this study in the adsorption of mobile Cadmium, consequently, reducing its availability in the soil solution and preventing its absorption by plants.

Table 3. Advanced tukey's test for means of binding agents in the soil solution

Binding agents type	Cd means mg/Kg
Dolomite	0.029 c
Organic fertilizer	0.0372 ab
Charcoal	0.0392 a

Means followed by the same letter in the column are not statistically different at α 5%

The higher efficiency of dolomite compared to the other adsorbents is due to the presence of two positive ions, Magnesium (Mg^{2+}) and Calcium (Ca^{2+}) which plays a very important role in the increasing of soil pH. These results agree with those of Jan (1990), who found that soil pH is one of the most important factors determining the amount of soluble Cd in soil. Since dolomite is an inorganic compound, the activity of its positive ions is supposed to be immediate, taking more advantage in the immobilization process in comparison with activated carbon and organic fertilizer. Dolomite also has extra adsorbing sites that increase the binding capacity.

Considering that the incubation process in the laboratory took 24 days, probably the organic ligands of organic binding agents did not reach their maximal activity, as the process might need much time to get completed. However, the incubation period was in line with that recommended by series of similar studies. Additionally, the higher efficiency of dolomite on Cadmium adsorption is not only due to its binding capacity through positive ions of Calcium and Magnesium, but also it happens as a result of its great power to increase soil pH by considerable folds. Once soil pH is higher enough, immobilization of Cadmium on the soil matrix may take place (Siebers et al. 2013), or depend on the amount of total

Cadmium in the soil and the pH level can also take place the precipitation of Cd to the lower layers usually at soil pH equal or higher than 8 (Alloway 1995).

However, the increase of soil pH does not always decrease the amount of Cadmium taken up by plants. It happens because, under field conditions, the absorption of Cadmium by plants can be affected by many variables such as soil factors and climate of the region (Tran and Popova 2013). In addition, Li et al. (2005), observed that plant genotype is very determinant on the amount of Cd taken up and accumulated in the plant organs, thereby, different species and varieties may take in different amounts of Cd.

The effect of combined factors or the interaction between factors on the adsorption of exchangeable and water soluble Cadmium was investigated. The factors are soil type with three levels and binding agents with also three levels. The interactions are described as follows in **table 4**. (1) Dolomite x Inceptisol; (2) Activated carbon x Inceptisol; (3) Organic fertilizer x Inceptisol; (4) Dolomite x reddish brown Alfisols; (5) Activated carbon x Ultisols; (6) Organic fertilizer x Ultisols; (7) Dolomite x Ultisols; (8) Activated carbon x reddish brown Alfisols, and (9) organic fertilizer x reddish brown Alfisols.

The results showed that the immobilization of exchangeable and water soluble Cadmium responded differently under different groups of combined factors formed by soil type and binding agent type. Based on the group of means derived from Tukey's test, the combination number 4 (Dolomite x reddish brown Alfisols) from Bakalan village indicated the highest performance on Cadmium adsorption (table 5) with an efficiency of 95.43% of all, followed by combinations number 6 (Organic fertilizer x Ultisols) and 1 (Dolomite x Inceptisol) with efficiencies of 92.64% and 92.11% respectively. Contrary, the interactions (3) of organic fertilizer x Ultisols and organic fertilizer x reddish brown Alfisols showed the lowest efficiency values of 89.30 % and 89.68% correspondingly. Despite these combinations having shown the lowest values among the all possible combinations, their efficiency is still remarkable. Our findings showed evidence of the results of Angelova et al. (2015), who observed the high efficiency of organic amendments on Cd immobilization in a pot experiment.

Table 4. Advanced Tukey's test for Cd in soil solution versus combined factors

Interaction	N	Mobile Cd
(3)Organic fertilizer x Inceptisols	3	0.0428 a
(9) Organic fertilizer x reddish brown Alfisol	3	0.0423ab
(5)Charcoal x Ultisols	3	0.0373bc
(7)Dolomite x Ultisols	3	0.0372bc
(2)Charcoal x Inceptisols	3	0.0371c
(8)Charcoal x reddish brown Alfisols	3	0.0352cd
(6)Organic fertilizer x Ultisols	3	0.0324cd
(1) Dolomite x Inceptisols	3	0.0316d
(4) Dolomite x reddish brown Alfisols	3	**0.0201**e

Means followed by the same letter are not statistically significant at α 5% for tukey's test

In soils from Kemuning (Inceptisols), the best combination was found at the treatment with dolomite (92%) compared to 90.72% of Charcoal and 89.30% of organic fertilizer. While in soils from Bakalan (reddish brown Alfisols), the best combination was the dolomite treatment with an efficiency of 95.43% compared to 91.53% and 92, 64% of activated carbon and organic fertilizer respectively. Dolomite also was greater in combination with Ultisols from Tamansari having performed at 91.40% paralleled with activated carbon 90.92% and organic fertilizer 89.68% in that order, combined with the same soil type. However, it is believed that clayey soils, and those containing Iron oxides like Ultisols from Tamansari, can immobilize metals, requiring higher amounts of dolomite or other limes compared to sandy and loamy soils (Suda & Makino, 2016). Similar findings were revealed by Reddy *et al*. (2014). They studied the efficiency of Zeolite and lime on the removal of Cd from wastewater. The results were 88% and 96%, respectively.

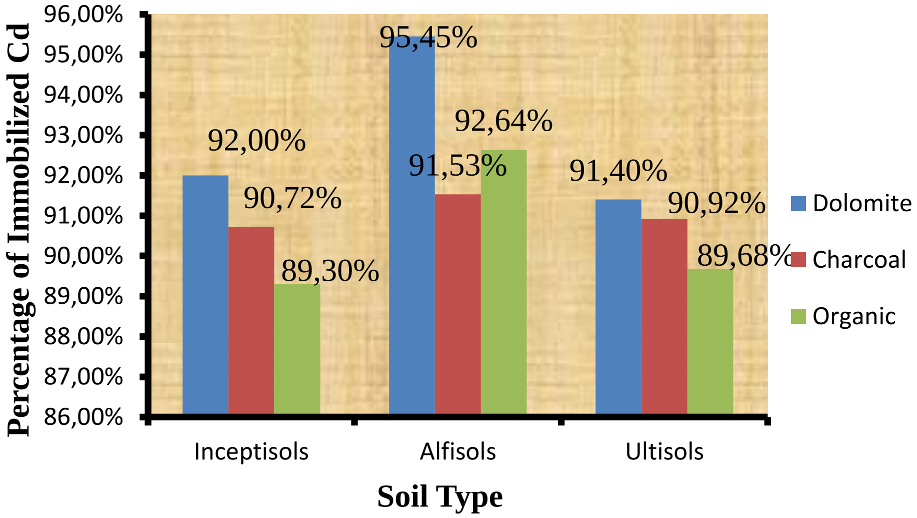

Figure 1. Combination of Soil and Adsorbents versus Immobilized Cd

In general, dolomite performed much better than the other treatments in combination with all types of soil, nevertheless, the other combinations of activated carbon and organic fertilizer with the respective soil types can also be recommended for implementation. Consequently, still early to conclude that dolomite is the best amendment, although, the results indicate so. Therefore, social and economic aspects should be weighed up, and deliberately take a concise decision based on the capability of the farmers as well as environmental sustainability. Therefore, further assessments are required in the next chapters.

The mobile Cd levels found in the soil solution after the soil having been ammended with three different binding agents in separate are displayed below (figure 2). Considering initial total Cd concentrations of 0.4, 0.41 and 0.44 mg Cd/kg in each soil, it is quite clear that the level of remaining Cd in soil solution is extremely low. The values range from 0.0201 to

0.0428 mg Cd/kg. These concentrations are not reported to cause a toxic effect on plants, and even accumulate along the food chain.

The greater efficiency of the combination (Dolomite × Alfisols) rivalled with all the remaining combinations. It might be supported by three reasons. First, the dolomite inorganic properties allow it to respond expeditiously as its positive ions (Ca^{2+} and Mg^{2+}) are rapidly released to participate in the binding bonds, not only, but dolomite also increases soils pH which is a contributing factor on the dynamic of Cadmium in the soil. Secondly, the reddish brown Alfisols from Bakalan is the one that exhibits the highest organic matter value. High or optimal contents of soil organic matter have the capability to bind a wide range of heavy metals including Cadmium through their carboxyl and hydroxyl ligands. Soil organic matter and organic fertilizers have been reported to also bind non-exchangeable Cadmium, impacting straightforwardly on the total Cadmium and exchangeable Cadmium in soil (Angelova et al. 2013).

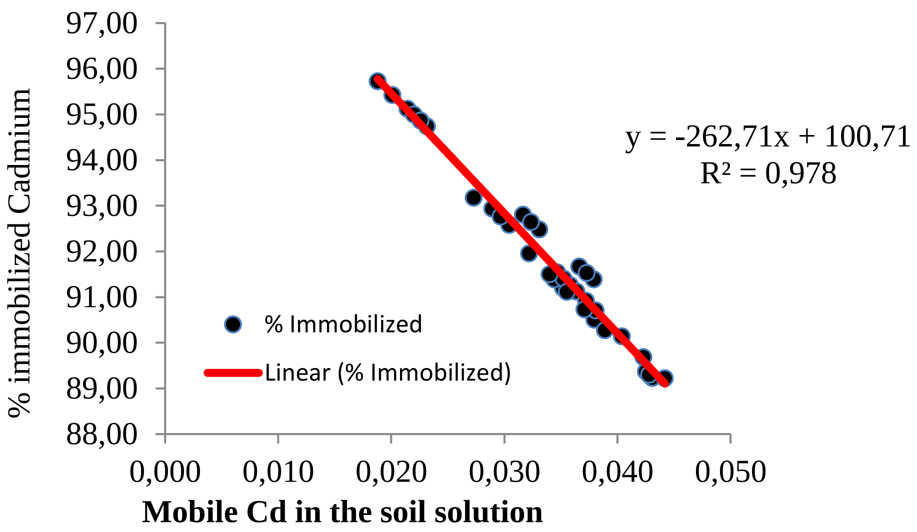

Figure 2. Mobile Cd in the Soil Solution versus percentage of Immobilized Cd

Sources of organic matter such as animal manure and crop straws are low-end, highly available and may feasibly provide a sustainable solution for soils contaminated with heavy metals including Cadmium and other agro-chemicals (Sun et al. 2014). Furthermore, Suave et al. (2003) cited in Sun et al. (2014) also evidenced that organic material is 30 times more effective on soil heavy metals adsorption than clay minerals. Similar results were found by, Luo et al. (2010). They observed that addition of compost into soil reduced mobile Cd levels by 70%. However, poultry manure has been indicated as having a different effect from other animal manure, as it increases Cadmium absorption by plants. The mechanisms behind this unusual effect still unknown, although can be suspected to be due to its pH level, which can be supposedly lower enough to favor desorption process, leading to the high availability of heavy metals in the soil solution. However, is still has to be investigated.

Finally, this study found evidence indicated in previous researches that the soil type is unequivocally fundamental on the immobilization of Cadmium, governed by its physical and chemical properties such as pH, organic matter, and clay content. On the other hand, the characteristics of the adsorbent applied to the soil are of worthy importance in view of the fact that it reacts diametrically with the soil, then shaping new physical and chemical soil characteristics.

3.3 Analysis of soil pH treated with binding agents

Soil pH of three types of soils was measured after 24 days of incubation. The soils were treated with three binding agents separately.

The effect of three different adsorbents or binding agents is shown in table 7). The results show that dolomite and activated carbon statistically have the same performance in rising soil pH in every soil types. Even though, in terms of mean values, soils ammended with activated carbon, indicate pH values slightly higher than those of soils corrected by dolomite.

Table 5. Advanced tukey's test for soil pH average

No	Adsorbent	pH means
1	Dolomite	7.60 ab
2	Charcoal	7.87 a
3	Organic fertilizer	7.11 c

Means followed by the same letter are not statistically significant at α 5% for tukey's test

The influence of activated carbon and dolomite on soil pH uprising is testified in many studies like that of Rastija et al. (2014) in laboratory conditions, which revealed that liming has a significant effect on soil pH by increasing progressively with the liming rate, having brought the pH to a neutral level. Their study not only noticed the role of lime on pH, but also observed its contribution on the availability of soil nutrients such as Ca, P, K, and Zn. On the other hand, took place a reduction of micronutrients Fe, Mn, and Aluminum exchangeable in the soil solution. Before liming, the soil pH was measured in 4.2, 3.74, 4.60 and 5.15. However the application of dolomite in the different experiments increased soil pH to the level of 6.87, 6.36, 7.00, and 7.32, and in the meantime, the availability of phosphorus increased by 45%, 33%, 8%, and 32% respectively. Therefore, the results of this research are in line with those reported by Rastija et al. (2014), having significantly increased the soil pH from 5.8 to 7.60.

The findings of this study using activated carbon derived from charcoal found an evidence of the capability of carbonaceous to increase soil pH by raising soil pH from 6.27 to 7.87. In contrast, Brennan et al. (2014) found no detrimental effect of activated carbon derived from coconut shell on soil pH. However, they justified their results based on the application rate, and also recommended a need for testing the activated carbons from different sources as are supposed to show varied potentials on soil pH amendment.

The organic fertilizer amendments also resulted in an increase of soil pH to a neutral level (7.11), but still not clear what causes such increase of pH. The function of organic fertilizer is similar to that of soil organic matter, which is to work as a buffer, preventing big variations of soil pH (Angelova et al. 2013), improve soil structure, nutrients availability, and consequently water retention capacity and optimal microbial activity (Reeve et al. 2013). However, organic material has been also indicated as an acidifying driving force through organic acid ligands in their structures, and this matter is discussed by many soil scientists showing convergences and divergences. A study was done by Zhang et al. (2006) cited in Sun et al. (2014), demonstrated that manure application increased soil pH by 1.2, and similar results were observed when the soil was ameliorated with other organic materials. Accordingly, these results can be paralleled with those of Zhang et al. (2006) due to the fact that also used organic fertilizers derived from manures. In addition, the uprising of soil pH treated by organic fertilizer might be due to the presence of considerable percentage of cations such as $Mg^{2+,}$ Ca^{2+} in the organic fertilizer. This fact is sustained by the fact that some organic fertilizers available in Indonesia have high pH values, for instance, the pH of the petro organic fertilizer commercialized has a pH value of 8, therefore, in contact with soil may contribute to increasing soil pH.

4 CONCLUSION

Dolomite was the best binding agent on immobilization of Cd (95.45%) in each soil, followed by organic fertilizer (92.64%) and charcoal (91.53%). However, in general, all the binding agents showed remarkable efficiency on Cd immobilization in three soil types. The results represent a huge gain to the researched communities in particular. There are also easily applicable and may increase significantly environmental performance. On the other hand, it may prevent soil degradation and pollution, in the meantime address climate change.

We recommend that farmers apply dolomite and organic fertilizer in the first campaign, and only organic fertilizer in the following campaigns, particularly in Kemuning and Bakalan to raise soil pH. In the following campaigns, only organic fertilizers could be applied to buffer soil pH while supplying nutrients to plants, and adsorbing Cd. On the other hand, other binding agents should be investigated in combinations to identify synergies or antagonism, which can impact on their efficiency.

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6 CONFLICT OF INTEREST

We declare no conflict of interest among the authors involved in this research.

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